THE HEAT INSULATING PROPERTIES OF COMMERCIAL STEAM PIPE COVERINGS

A THESIS

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CONTENTS

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I. Introduction.

The necessity for insulating steam pipes against the loss of heat was not recognized during the earlier days of the use of steam as a medium for the transmission of energy; nor was the need as great then as it is now on account of the lower cost of fuel and the lower difference of temperature between the steam and the air outside the pipe. But the advent of higher pressures, superheat, and longer steam lines brought in the use of a miscellaneous lot of materials for the covering of steam pipes. At the present time, there are on the market a large number of different kinds of pipe coverings, and when designing a plant or steam pipe line the pertinent questions for the engineer to ask are: "What kind of commercial covering shall I use? Which one combines the qualities of durability and cheapness with good heat insulating properties in such a way as to give the greatest net return on the investment?" It is in the attempt to answer such questions as these that this paper is written.

II. Former Investigations.

It is not claimed that this is the first work that has been done in the given field--In fact,an enormous amount of effort has been expended in attempts to determine accurately the savings that would be effected by the use of nonconducting coverings on steam pipes. Even with these results available,little reliable data is at hand on the efficiency of pipe coverings in commercial use at the present time. However,a brief discussion of some of the more important of the investigations on the subject will serve as a good introduction to the work in hand.

The first extensive investigation of materials used for the purpose of insulating steam pipes against the loss of heat was made by Prof.J.M.Ordway,and the results were published in three papers before the American Society of Mechanical Engineers.* His method consisted of covering a steam pipe with a given thickness of the material to be tested,and then surrounding this with a calorimeter which consisted of a double cylinder with the space between filled with water. The amount of heat passing through the covering was calculated from the weight of water and its rise in temperature in a given time. In the third paper a comparison was given,between results obtained by the above method and those where an attempt was made to determine the loss of heat through the covering by measuring the amount of condensation in the pipe under certain fixed conditions of test. The conclusions even at that early day were decidedly against the condensation tests. It

*Trans.A.S.M.E.,Vol.5 p.73; Vol.5 p.303; and Vol.6 p.168

was shown that such tests could not be depended upon for highly accurate results.

The work of Prof.Ordway is of interest principally on account of the great variety of materials tested--some fifty-five in all. However,many of them were not useful as pipe covering materials; as for example,common salt,cotton batting,anthracite coal,geese feathers,etc.

The principal objection to the method used is that the covering was not made to work under the same conditions that would prevail if it were on the pipe without the surrounding calorimeter. It would be a rare accident,indeed,if the temperature of the air adjacent to the covering were the same with Ordway's calorimeter in place as when the pipe was in the open air. Since the amount of heat lost is a function of the difference of temperature between the steam and air,and not of the steam temperature alone a serious error might be introduced here. A further and equally important source of error lies in the fact that the calorimeter serves itself as an insulator to a limited extent. Anything that resists the passage of heat decreases the amount that would be lost from the pipe,and the metal of the calorimeter,and,what is more important,the inclosed air space would have quite an insulating effect. A minor error might be introduced by the transfer of heat from the calorimeter to the air and vice-versa.

Many more tests of heat insulating materials have been made by the condensation method than by any other. A large number of papers have been published on such tests,and those of Brill,*

*Trans.A.S.M.E.,Vol.XVI.,p.827

Barrus* and Eberle** are among the more widely knqwn. The difficulties in the way of getting very accurate results from condensation tests are at once apparent. The amount of heat represented by the condensation of a single pound of steam is so large that, in order to get reasonably accurate results, very long lengths of pipe must be used, so as to increase the amount of condensation to a measurable quantity. This introduces differences in couplings, bends, etc., that are hard to correct for; because the losses per square foot are rarely the same at these points as for the rest of the pipe. It is true that such fittings are found on every installation of steam piping, but not necessarily in the same proportion as on the test apparatus. A large source of error is in the fact that the quality of the steam is a quantity hard to determine with great accuracy, owing to the difficulty of getting an absolutely correct sample. If dead steam is used in the pipes then only one quality need be measured, namely, that of the entering live steam. In this case it is likely that air and condensation will collect in the pipes at low points and seriously affect the radiation from such parts. If a current of steam is maintained the quality must be measured at exit, as well as the amount of steam circulated. The matter of collecting and weighing the steam condensed in the pipe is neither accurate nor convenient. The arrangement of the ends of the pipe and of the collecting apparatus so that no heat can be lost from them is not possible by the use merely of insulating materials. The best

*Trans. A.S.M.E., Vol. XXIII., p. 846
**Mit uber Forschungs-Arbeiten auf dem Gebeite des Ing.

proof of the inaccuracy of the condensation methods is that different experimentors using them are able only approximately to check each other or even their own results.

An interesting departure from previous methods was that of Mr.C.L.Norton* of Mass.Inst.of Technology. An electric heater consisting of coils of resistance wire was placed in a pipe filled with oil,and the pipe was then covered with an insulating material. Current was passed through the coils,and the amount of energy required to hold the temperature of the pipe constant was ascertained. This method was capable of giving very accurate results,but as employed by Mr.Norton,it was not applicable to commercial coverings on account of the necessity of covering the ends with the same material as that on the main body of the pipe. Other reasons why the highest accuracy could not be obtained by it were the extremely small size of the sections of pipe used and the fact that the temperature was measured at the upper end by means of a mercury thermometer.

Perhaps the most accurate results of pipe covering tests yet published were those of Mr.H.G.Stott** of the Manhattan Railway Co.,New York. Several different kinds of coverings in sections of I5 feet each were placed on a long line of 2 inch pipe,which was heated by passing a current through the metal of the pipe; the pipe itself serving as an electric heater. The heat given to each individual covering was calculated from the product of

*Trans.A.S.M.E.,Vol.XIX.,p.387
**Power I902

the current in the pipe and the voltage drop in an eleven-foot section under the given covering. The method of measuring the temperature was unique, since the section of pipe under the covering was made to serve not only as a resistance, but also as a resistance thermometer; the temperature being calculated from the change in resistance of the pipe.

As far as they went these tests were highly accurate, and practically the only objection that can be offered is the tremendous amount of current required. This would limit the size of the covering to be tested to practically the 2 inch size used by Stott, and while the results would be excellent on a comparative basis there is no ground for the assumption that there is the same loss through a square foot of say IO inch covering as through a square foot of 2 inch covering of the same thickness, when, in the latter case, there is a much greater volume of material for the given pipe area.

III. Fundamental Methods of Test.

It has already been pointed out that the methods employed by Norton and Stott were open to criticism. However, the principles on which their methods were based seemed fundamentally correct, and were therefore adopted as a basis for this investigation. An original scheme of performing the tests was adopted and by this means all points of criticism were eliminated.

It was proposed to heat a section of covered pipe by means of an electric heater made up of resistance coils inside the pipe, and to calculate the amount of heat lost through the covering by

measuring the energy required to hold the outside metal of the pipe at a constant known temperature. Under such conditions it is evident that just enough energy is being supplied to compensate for the losses through the covering. Otherwise the increase or decrease of energy would cause the pipe to heat up or cool off as the case might be.

It is argued by many that covering tests should be made on steam pipes in order that operating conditions be obtained. But operating conditions can be duplicated exactly,so far as the covering is concerned,without having steam itself in the pipe; for it can make no possible difference in the rate of heat flow through the pipe covering material itself,whether the heat supplied to the metal of the pipe is from steam or any other source, so long as the temperature of the outside of the pipe is constant and is definitely known. The phenomenon is one of the flow of heat and there is no condition of temperature or heat flow that will be different outside of the pipe when electrically heated than when it is steam heated. The fact that the transfer of heat from steam to the pipe is capable of greater speed than from oil or some other medium to the pipe,has no effect on the rate of heat flow through the covering,provided that the temperature of teh outside of the pipe remains constant.

The application of the electrical method of heating required that an accurate means be devised for the purpose of telling not only when the temperature of the outside of the pipe was constant, but also the actual value of this temperature. The means proposed for this was the thermoelectric couples placed on the pipe at

a sufficient number of places that a correct average temperature of the outside of the pipe might be ascertained.

IV. Preliminary Experiments.

As an aid in applying the results obtained from electrical methods to steam pipe conditions, it was necessary to know definitely the relation between the temperature of the steam inside of a pipe and that of the outside surface of the pipe itself under different conditions of pressure and temperature. Prof. Norton assumed that the temperature of the outside of the pipe was the same when it contained oil as when it held steam, the steam and oil being at the same temperature. Hence, he determined only the temperature of the oil, and used this in his calculations, neglecting entirely the consideration of the difference in temperature gradients from oil to outside of pipe and from steam to outside of pipe. Stott's results imply the assumption that the temperature of a steam pipe is the same as that of the steam in the pipe which is not in strict accordance with the facts.

Several different methods of tests were tried to determine accurately the exact difference in temperature between the steam inside the pipe and the outside metal of the pipe, both with the pipe covered and uncovered. It was first attempted to measure the two temperatures by means of copper-iron thermo-couples. However, it was found in the calibration of these couples that the curve between milli-volts and temperature reversed its direction at between 300 degrees F. and 400 degrees F.; so that these could not be used for the temperatures that were desired, some of which

lay between these limits.

Mercury thermometers were tried; one being placed in a well in the steam pipe,and another cemented to the pipe with white lead so as to give good contact. These gave surprising results. Apparently the temperature of the outside of the pipe was greater than that of the steam itself. The obvious error was due to the fact that the reading of the thermometer in the well was too low; partly because of the stem error and partly on account of the greater radiation from the top of the well than from the covered pipe. This test proved conclusively that for the work in hand mercury thermometers were not at all reliable.

In this connection,reference is made to Duchesne's experiments on superheat.* In these experiments it was found that sometimes a difference of more than 80°C.(144°F.) existed between the temperature as measured by a very sensitive theromo-couple and the reading of a thermometer in its well.

It was next proposed to use copper-nickel couples arranged in opposition with a very sensitive galvanometer in series with one of the leads. One couple was to be placed directly in the steam and the other to be soldered to the pipe,and the difference of temperature proportional to the deflection of the galvanometer could be determined. But the difficulties had not all been surmounted when the temperature measuring device had been selected. It was necessary to calibrate the couples,so that the temperature difference corresponding to a given deflection of the galvanometer would be known; and,since the deflection per degree is not the

*Power; July 23,1913

same at low as at high temperatures it was essential that the couples be calibrated for difference of temperature at each temperature at which tests were desired. In other words, the thermo-element was for measuring differences of temperature up to about 30°F., and if one couple were at 200 and the other at 2I0°F. there would not necessarily be the same deflection as if one were at 400 and the other at 4I0°F., though in each case the difference of temperature is the same.

At first oil baths heated with Bunsen burners were tried as the means of holding each couple at a constant temperature while the deflection and difference of temperature could be read. However, it was found to be impossible to stir the oil fast enough to maintain a uniform temperature throughout the bath. The thermo-elements were so sensitive that they would cause considerable deflections when mercury thermometers would indicate no change of conditions. This difficulty was overcome by using for one bath a flask containing a quantity of pure substance whose boiling point is fixed and is at the required temperature. The second temperature was obtained by the use of a bath similar to the above, but having dissolved in a portion of the original pure substance some other material of higher or lower boiling point. By placing one couple in each of the above flasks the temperature difference between them could be varied from zero to the amount of the total difference between the boiling points of the two substances used. For example, when aniline was the pure substance originally contained in the two flasks it was easy to vary the boiling point of the liquid in one of them by adding to it, in small quantities at a time, some naphthaline.

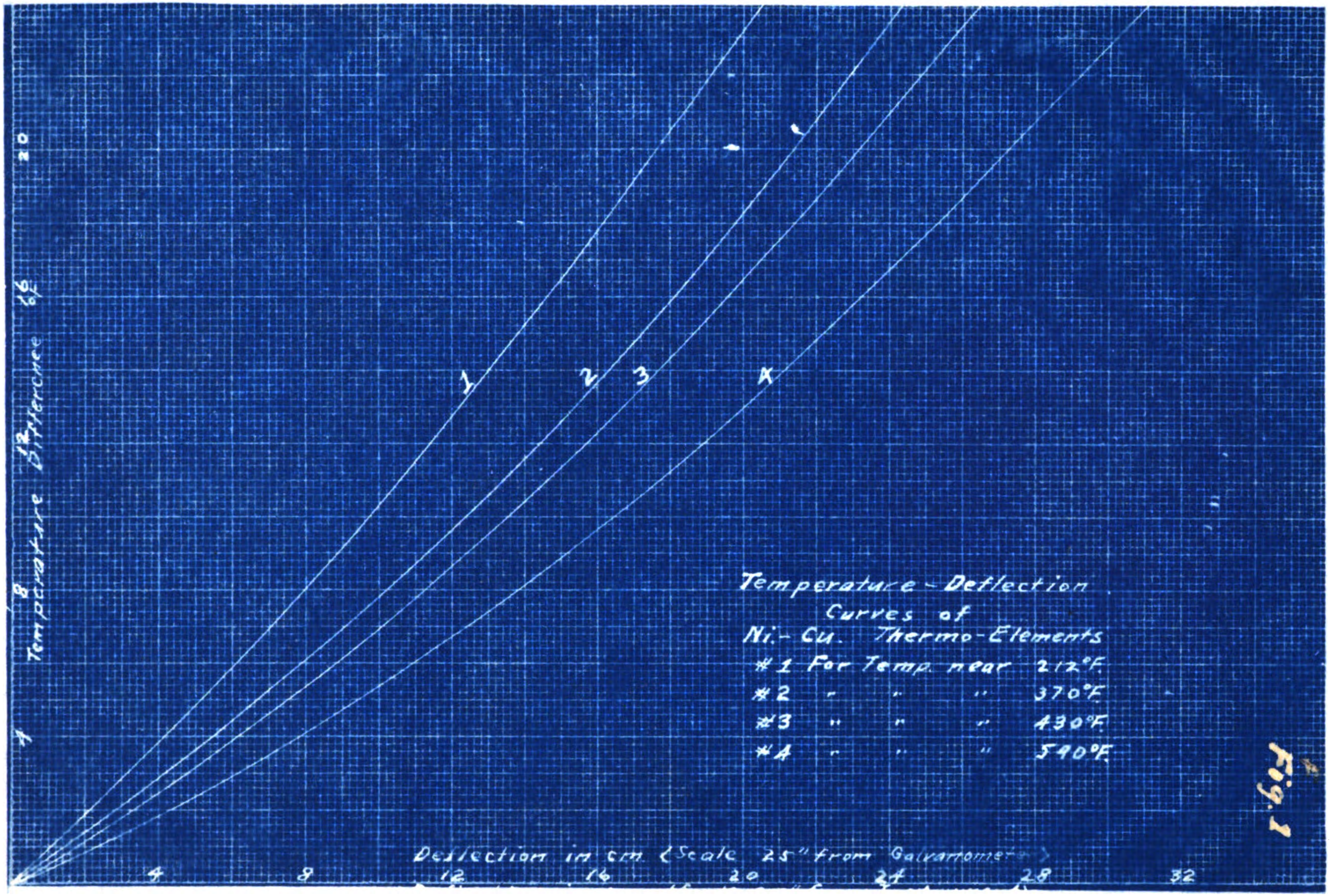

Temperature - Deflection
Curves of
Ni.- Cu. Thermo-Elements
#1 For Temp. near 212°F.
#2 " " " 370°F.
#3 " " " 430°F.
#4 " " " 540°F.
1
2
3
4
Temperature Difference °F
4
8
12
16
20
Deflection in cm. (Scale 25" from Galvanometer)
4
8
12
16
20
24
28
32

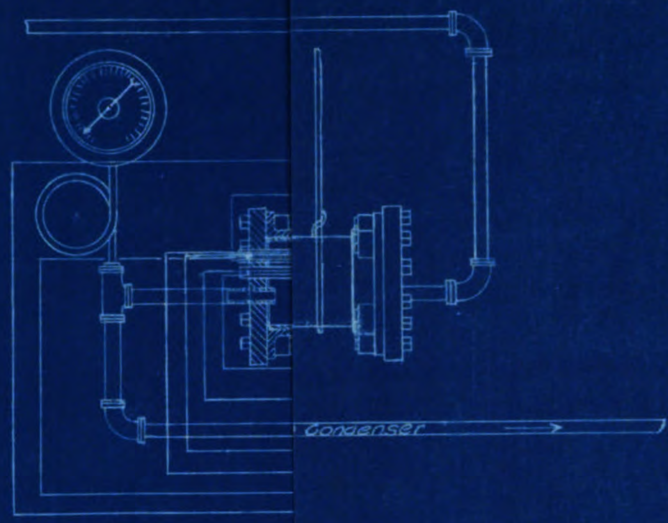
Fig. 1

The elements were calibrated for temperatures near 212°F., using pure water for one bath and a mixture of alcohol and water for the other. For temperatures near 370°F. boiling aniline was used for the constant temperature bath and a mixture of aniline and naphthaline for the variable temperature bath. At 430°F. the baths were pure naphthaline and a mixture of naphthaline and di-phenyl-amine, and at near 590°F. anthracene and naphthaline were used in mixtures of varying proportions for both baths. The curve between temperatures as ordinates and galvanometer deflections as abscissae are shown in Fig. I.

The problem of carrying through the pipe the leads of the couple that was to be in the steam and yet keeping the wires insulated from the pipe and from each other was not a simple one. The device that finally proved to be satisfactory was made by screwing a 3/8 inch nipple into a I/2 inch bushing in a reverse manner, passing the couple through the nipple, and filling the space that remained with "Bakelite." The plug thus formed was heated for several hours at about I75°F. after which it was ready to be put into the pipe, in which a I/2 inch tapped hole had been provided. It was found that such a plug would hold perfectly tight for all pressures that were used and these went as high as I50 pounds gage.

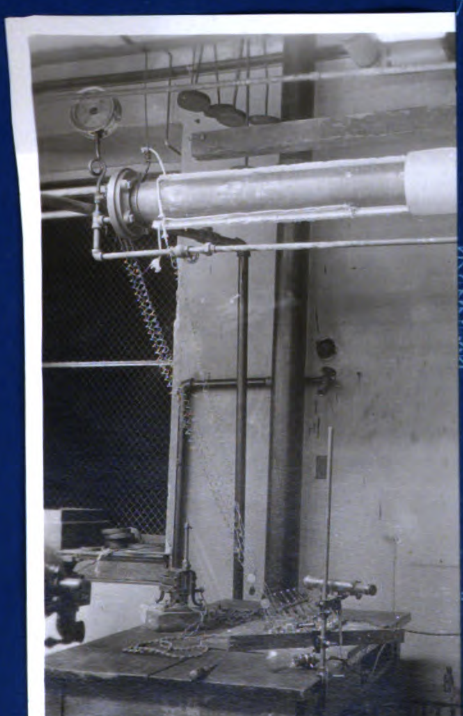
The first tests were made on the steam line in the University pump house tunnel, where it was hard to set up the instruments properly; and, worse than that, it was not possible to remove the plug when something went wrong without being greatly delayed on account of the impossibility of shutting off the steam at will.

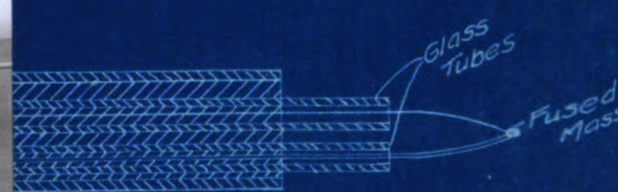
Fig. 2



MINING DIFFERENCE OF

TSIDE OF PIPE (SCALE 1"=1')



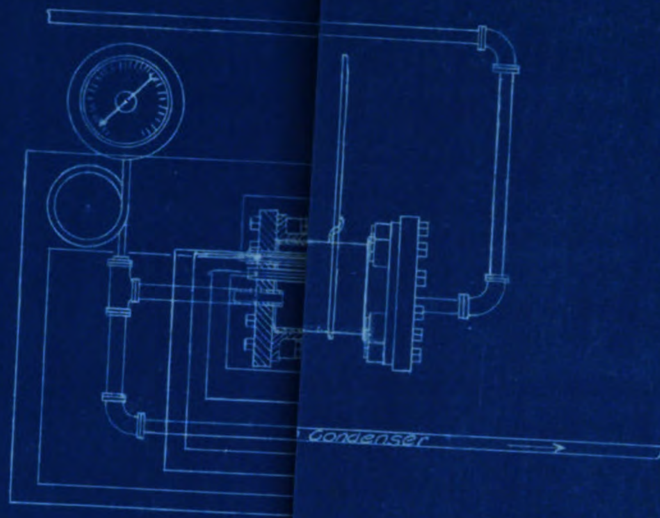


F CONDUCTORS

Henry Rekerodres

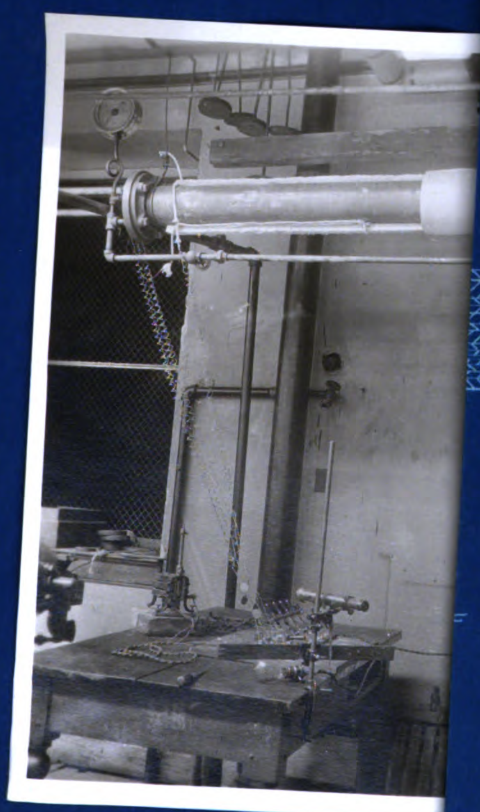
Fig. 3

Fig. 2



MINING DIFFERENCE OF

TSIDE OF PIPE (SCALE 1"=1')



F CONDUCTORS

Fig. 3

Henry Rekerodres

These difficulties led to the installation of a section of pipe in the Steam Laboratory at which the pressure could be regulated at will, and which could be covered in any manner desired. Fig.2 shows a diagrammatic sketch of the pipe and its connections. The long length of small pipe carrying the steam to the large pipe was bare so that there was no likelihood of getting superheated steam in the test section. A drain running from the bottom of the pipe flange to a condenser was put on to remove the condensed steam. A small amount of steam was kept flowing in this pipe all the time so that no air would collect in the pipe. Fig.3 is a photograph showing the pipe and the instruments for measuring the temperature difference between steam and pipe. Half of the end section of covering is removed to show the location of the couples on the outside of the pipe.

In order to be entirely sure that no short circuit would occur, it was found necessary to place the wires in glass tubes before putting them through the plug and to use the "Bakelite" merely as a cement to fill the spaces and stop the passage of steam. The other couple, the one that was soldered to the pipe, was insulated by covering the leads with asbestos tubing. In the final arrangement of this steam test pipe there were two sets of thermo-couples each having one couple in the steam and another soldered to the outside of the pipe, and a third set having one couple in the steam and the other soldered to the inside surface of the pipe. The readings taken with these couples were very consistent with each other, but seemed to show that there was a comparatively large drop in temperature through the metal of the pipe, about 2

to 3° F. at a steam pressure of I40 pounds gage, and with covered pipe. This is not in accordance with data on the subject obtained from former investigations* and while that is not sufficient reason for discrediting the results, there is a possibility that the wires of which the couples were made were of such size that a considerable amount of heat might be conducted away from the couple on the outside of the pipe thereby lowering the temperature of that couple itself the small amount necessary to cause the discrepancy found in the results. Eberle** found that with covered pipes and saturated steam the difference in temperature between steam and outer surface of the pipe varied at different pressures from 0.7° F. to I.80° F. It is certain, therefore, that the temperature difference between steam and the outside surface of a pipe is quite small for saturated steam, and that no error in excess of I% will be made by assuming, as Stott did, that the steam and pipe were at the steam temperature.

With superheated steam, on the other hand, Eberle has shown that the drop in temperature from steam to pipe is sometimes over I00° F. in the case of bare pipe, and even with the covered pipe it may be as high as I2° F. A considerable error would therefore be introduced if pipe and steam temperatures were assumed the same.

The large difference of temperature between superheated steam and the outside walls of the vessel containing it partially accounts for the higher economy obtained by the use of superheat. It is certain that there would be less heat losses from a pipe

*Mit. uber Forchungs-Arbeiten auf dem Geb. des Deutch Ing.; Heft 58, seite 20 und seite 5I.
**Ibid.

line carrying superheated steam than one carrying saturated steam at the same steam temperature. In the first case the outside of the pipe would be cooler than in the second case,and the loss is dependent upon the temperature of the outside of the pipe and not the steam. The radiation losses from engine cylinders would be less for the same reason as above. Also there would be lower losses due to the heating and cooling of the cylinder walls during the cycle; for the superheated steam would not heat them so hot,in comparison with its own temperature as would saturated steam. Investigations on temperature gradient from a vessel containing steam to the air outside,offers a promising field for study,and it is hoped that these investigations can be carried very much farther in the near future.

V. Description of Apparatus for Covering Tests.

The general arrangement of the apparatus for the tests of pipe coverings is shown in Fig.4. The long pipe is a standard 5 inch steel pipe,sixteen feet long,having a cap welded on to close one end with a flange welded on the other. This flange has a blank flange bolted to it carrying the following fittings: the stuffing box for the rod of the circulating propeller,the insulated terminals for the electric leads,and the nipple leading to the over-flow reservoir. The heating coils are inside the large pipe. They are made of nichrome wire and have four coils in parallel as shown in Fig.5 a and Fig.5 b.

At first tests were made using nothing in the pipe except air as a medium for carrying heat from the coils to the pipe. This

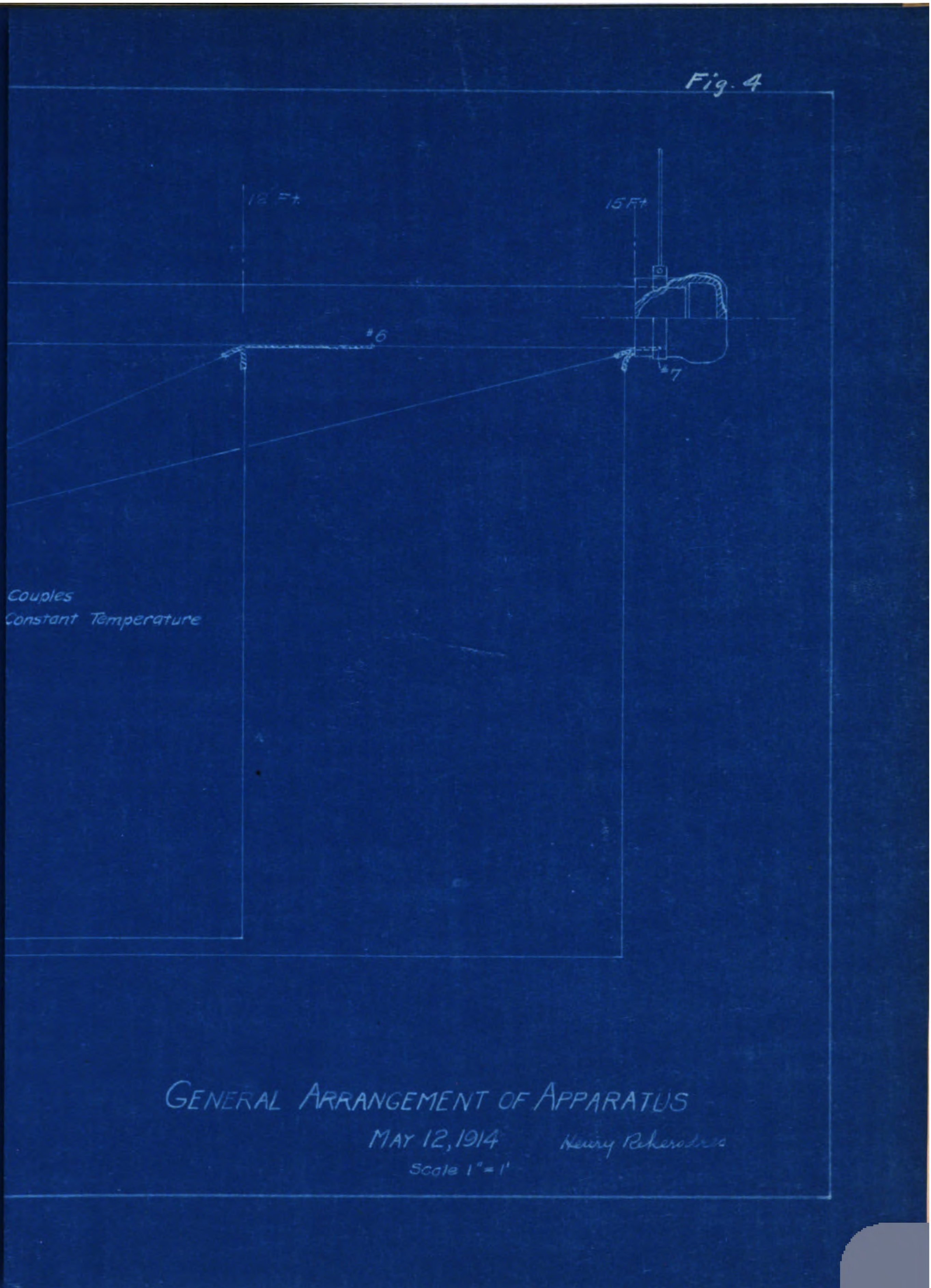


Fig. 4
18 Ft
15 Ft
#6
#7
Couples
Constant Temperature
GENERAL ARRANGEMENT OF APPARATUS
MAY 12, 1914
Scale 1" = 1'

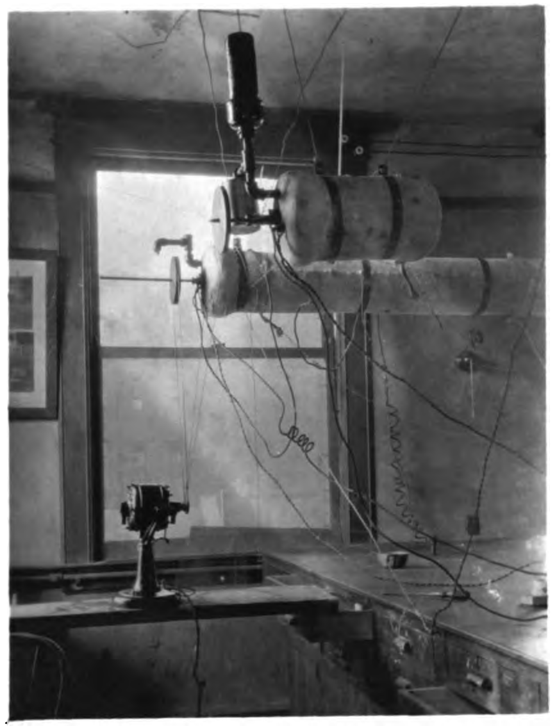


Fig.8

Fig.9

was not satisfactory; for the air was not a good conductor of heat, and the temperature of the pipe was much higher in the middle of its length than at the ends where radiation was greater. In order to insure a uniform temperature over the whole length of the pipe it was necessary to use something in place of the air that was a good conductor of heat, was a nonconductor of electricity, and had a high boiling point. Gas engine cylinder oil met all of these requirements and was therefore adopted. A fairly uniform temperature was further insured by installing the motor driven propeller shown in Fig.5 a. The propeller worked in an I$\frac{1}{4}$ inch pipe running nearly the whole length of the test pipe and the oil was forced down this pipe and allowed to return through the space containing the coils, between the small and main pipes.

The expansion reservoir shown in Fig.4 was for the purpose of keeping the test pipe full of oil. When the oil expanded due to heating it flowed out through the spout and on cooling, the spout could be closed and oil poured back into the pipe.

At each end of the pipe was a section of 85% magnesia covering leaving a test section of just I5 feet between them; which section would accomodate five lengths of standard pipe covering. The remaining portions of the ends were covered with plastic covering to a depth of about an inch. The pipe was suspended in a horizontal position by wires from the ceiling attached to steel bands placed around the short end sections of covering that remained in place throughout the entire series of tests.

Temperatures were measured by means of thermo-couples of the form already described on page 9. Seven of these were placed on the surface of the pipe in the positions shown in Fig.4; so that the average temperature of the test section was obtained with a high degree of accuracy. The method of fastening these couples to the pipe differed from that already described for they could not be soldered to the pipe on account of the high temperature used which would have melted the solder. A shallow hole was drilled into the pipe large enough to take the point forming the junction of thetwo metals of the couple,and after insertion the steel of the pipe was forced down against this point by means of a punch. An absolutely sure metal to metal contact was thus secured and the chances for a drop in temperature from the metal of the pipe to the couple were reduced to a minimum. The leads were insulated as in the previous case by covering them with woven asbestos tubing.

In this case the temperature of the pipe was measured by finding the difference between the outside of the pipe and a pure substance maintained in a boiling condition and whose boiling point was at the temperature near which it was desired to hold the pipe. The boiling point of the liquid was determined with great care. It was placed in a long-necked flask,and the temperature was checked by means of two standard thermometers. The vapor was boiled up high enough to cover the stems of the two thermometers used so that all stem error was eliminated. The readings of these thermometers checked very closely. One couple of each set was on the outside of the pipe and the other was in the constant temperature bath. The galvanometer deflection gave the difference in

temperature between bath and pipe surface,and knowing the temperature of the former,the temperature of the outside of the pipe could easily be found. The leads in the flask were insulated from each other by inclosing each nickel wire in a small glass tube and then passing a larger glass tube over this tube and the copper wire-thus completely isolating each wire as shown in Fig. 5 d.

Direct current at IIO volts was used for the tests. It was obtained during the day from the Electrical Laboratory of the University of Wisconsin and at night from the Curtis turbo-generator in the Steam Laboratory. The voltage from each of these sources was maintained very steady and very close regulation of the heating current could be secured by varying the external resistance in series with the heater coils. A water rheostat was first tried out as the external resistance,but it proved very unsatisfactory on account of the great variation in current as the water heated up. A wound wire rheostat made of three coils of number I3 Climax wire arranged in parallel was substituted for the water box. The rheostat is shown in the foreground of the photograph,Fig.7. One end of the coils was connected to the line while the other was left open,and the variation of resistance was obtained by changing the position of sliders to which was attached the lead from the rheostat to the pipe terminal. Very close adjustments could be obtained by this means. Smaller currents than obtained with all three in parallel could be secured with two in parallel and finally,for the smallest currents,all three could be connected in series. The Climax wire has the advantage that its resistance varies little with the temperature; so that with a

constant impressed voltage and a certain position of the sliders on the coils the same current would flow steadily for hours.

The instruments for measuring the energy to the pipe were a Weston D.C. voltmeter and a Weston D.C. milli-voltmeter and shunt for measuring the current. These instruments were calibrated at the Standards Laboratory of the University and the results of the calibrations are shown in the form of curves in the appendix.

The short pipe was an exact reproduction of the permanently covered ends of the test pipe. If the 15-foot test section already mentioned were cut out and the two ends of the test pipe brought together an exact duplicate of the short pipe would be obtained in so far as length, area exposed and covering are concerned. Certain changes had necessarily to be made in the heating coils in the short pipe and the circulating pipe was omitted. The variation of power in this small heater was effected by running the current through a lamp-bank, and for closer regulation than the lamp-bank would give, a small wire rheostat was used in parallel with the lamps.

All parts tending to increase the heat losses from the test pipe, such as the stuffing box for the propeller, the electric leads, etc. were reproduced in the short section as nearly like those on the test pipe as it was readily possible to make them. Therefore, the difference between the loss from the test pipe and that from the short pipe represented the exact loss from the 15-foot section covered with the five standard lengths of commercial covering.

The power required to drive the circulating propeller was extremely small as compared with the energy supplied to the heater

coils. It ranged from two to five watts,depending upon the temperature of the oil. Since there was a propeller placed in the short pipe of the same size and running at the same speed so that in the main test pipe,no correction was necessary for the heat given up by the stirring device. The same or nearly the same power was taken in each case; so that the effect of the power required to run the stirrer disappeared when the difference of losses from long and short pipes was considered.

VI. Method of Performing Tests.

The coverings,before being tested for their heat insulating qualities,were placed on the steam pipe already mentioned,Fig.2, and allowed to dry for a week. Steam in the pipe was kept at about I30 pounds pressure throughout that time,and as a result the coverings were thoroughly dry when placed on the test pipe. They were fitted carefully so that all joints were snug,and the canvas was pasted over the seams in the same manner as in power plant practice. The paste was allowed to dry thoroughly before the test began.

A comparatively high current was turned on until the pipe was heated to near the desired temperature,and then the current was lowered to such a value as would just hold the temperature of the outside of the pipe constant. When nearly the right temperature was obtained,a little lower current was used to see if the pipe began to cool and then a little higher to see if it heated up. When the correct current was determined,the outside of the pipe was held at a constant temperature for at least 30 minutes before

readings were taken. The room temperature was taken as the average of the readings of five thermometers at different points in the room and all about equidistant from the pipe. All windows and the door of the room was kept closed during the test to avoid air currents. There are few installations of steam piping that are not exposed to some air currents and it might seem that these currents should be present if actual working conditions are to be approximated. However,the circulation of the air is a factor that is very hard to keep constant,and furthermore,it would be different for nearly every different installation. Therefore, these tests have been made in as near perfectly still air as could be obtained by keeping the room tightly closed,and at some future date the effect of air currents may be investigated.

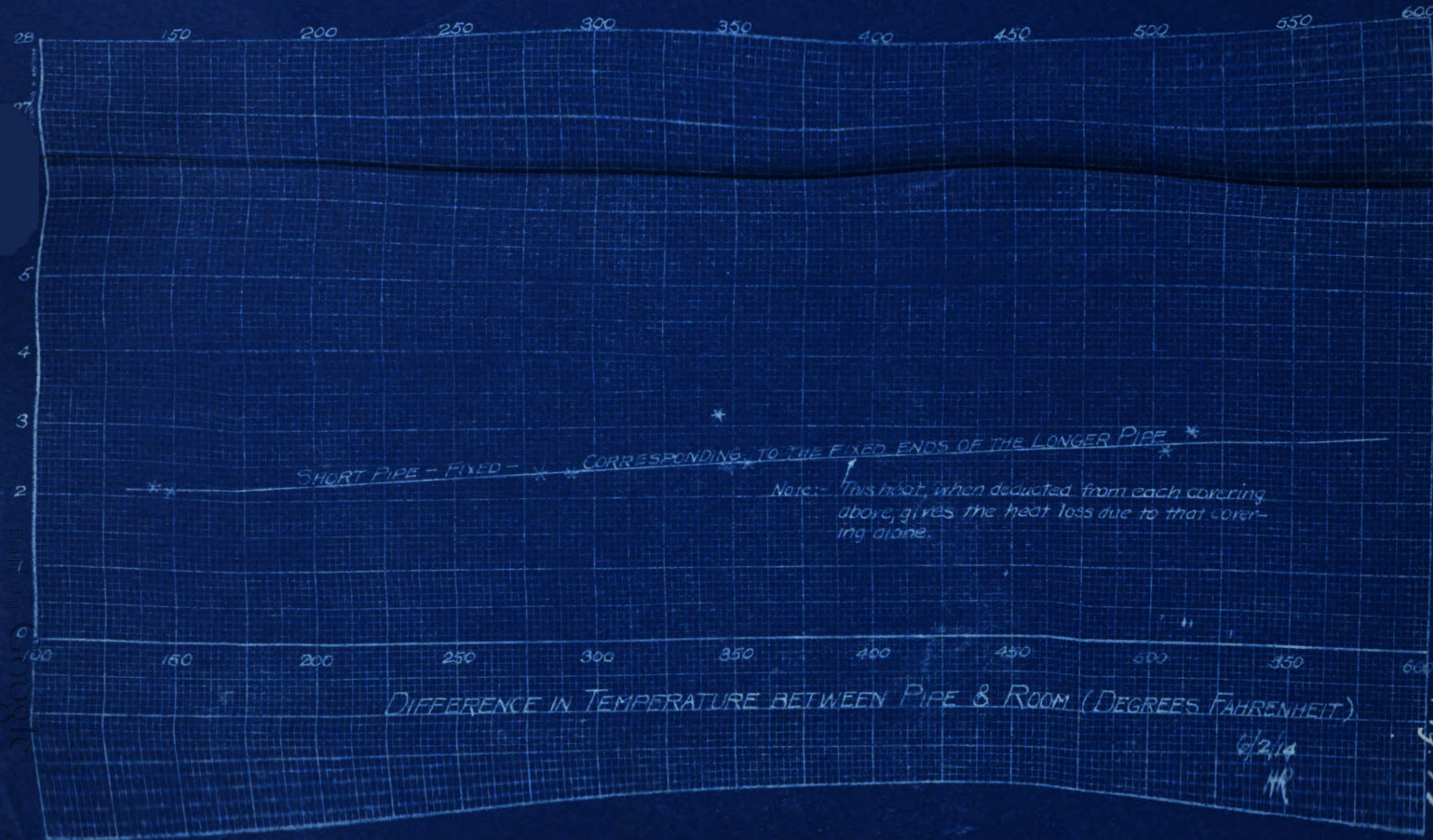
VII. Discussion of Results.

The tabulated results of the tests are shown in Fig.IO,while the relation between losses and temperature difference between outside of pipe and the air,is shown for the different coverings by the curves of Fig.II. The difference in ordinates between the curve for the long pipe and that for the short one represents the loss from the I5-foot length of covering being tested. This result divided by the area in square feet of thetest section gives the loss per square foot per degree difference of temperature shown by the curve in Fig.I3. From these curves one can tell at a glance which are the better and which are the poorer coverings. It is evident,from these results,that the 85% Magnesia and the Sponge Felt are the most efficient in the prevention of heat

DATA ON TESTS

Long Pipe	Covering Material (15 Ft bet. ends)	Test No.	Date 1914	Room Temp °F	Pipe Temp °F	Dif. in Temp °F	B.T.U. Loss / Hr.	B.T.U. Loss / Hr / ° Dif. in Temp.	Remarks
	J.M. "Sponge Felt"	1	Apr. 11	68.1	211.0	142.9	1418.	9.93	
		2	"	79.5	210.8	131.3	1280.	9.76	
		3	12	61.5	369.2	307.7	3728.	12.11	
		4	"	80.8	357.1	276.3	3126.	11.30	
		5	"	67.8	650.3	582.5	8318.	14.27	
		6	"	82.0	633.2	551.2	7800.	14.15	
	J.M. "Asbestocel"	7	18	74.4	214.7	140.3	1669.	11.89	
		8	"	83.5	209.0	125.5	1545.	12.30	
		9	19	74.7	371.3	296.6	4240.	14.27	
		10	"	80.4	397.0	316.6	4460.	14.06	
Short Pipe	Same as ends of Long Pipe	41	3	78.0	220.4	142.4	311.	2.18	
		42	6	82.5	220.9	148.4	309.	2.09	
		43	"	84.0	364.8	280.8	662.	2.36	
		44	9	86.0	377.7	291.7	688.	2.37	
		45	4	78.8	423.5	344.7	1085.	3.15	
		46	6	85.0	433.0	348.0	836.	2.40	
		47	9	85.5	440.5	354.9	886.	2.49	
		48	8	79.8	593.5	513.7	1516.	2.95	
		49	9	86.0	589.9	503.9	1335.	2.65	

Fig. 10



Short Pipe - Fixed - Corresponding to the Fixed Ends of the Longer Pipe
Note:- This heat, when deducted from each covering above, gives the heat loss due to that covering alone.
Difference in Temperature between Pipe & Room (Degrees Fahrenheit)
150
200
250
300
350
400
450
500
550
600
2
3
4
5
6/2/14

Fig. 11

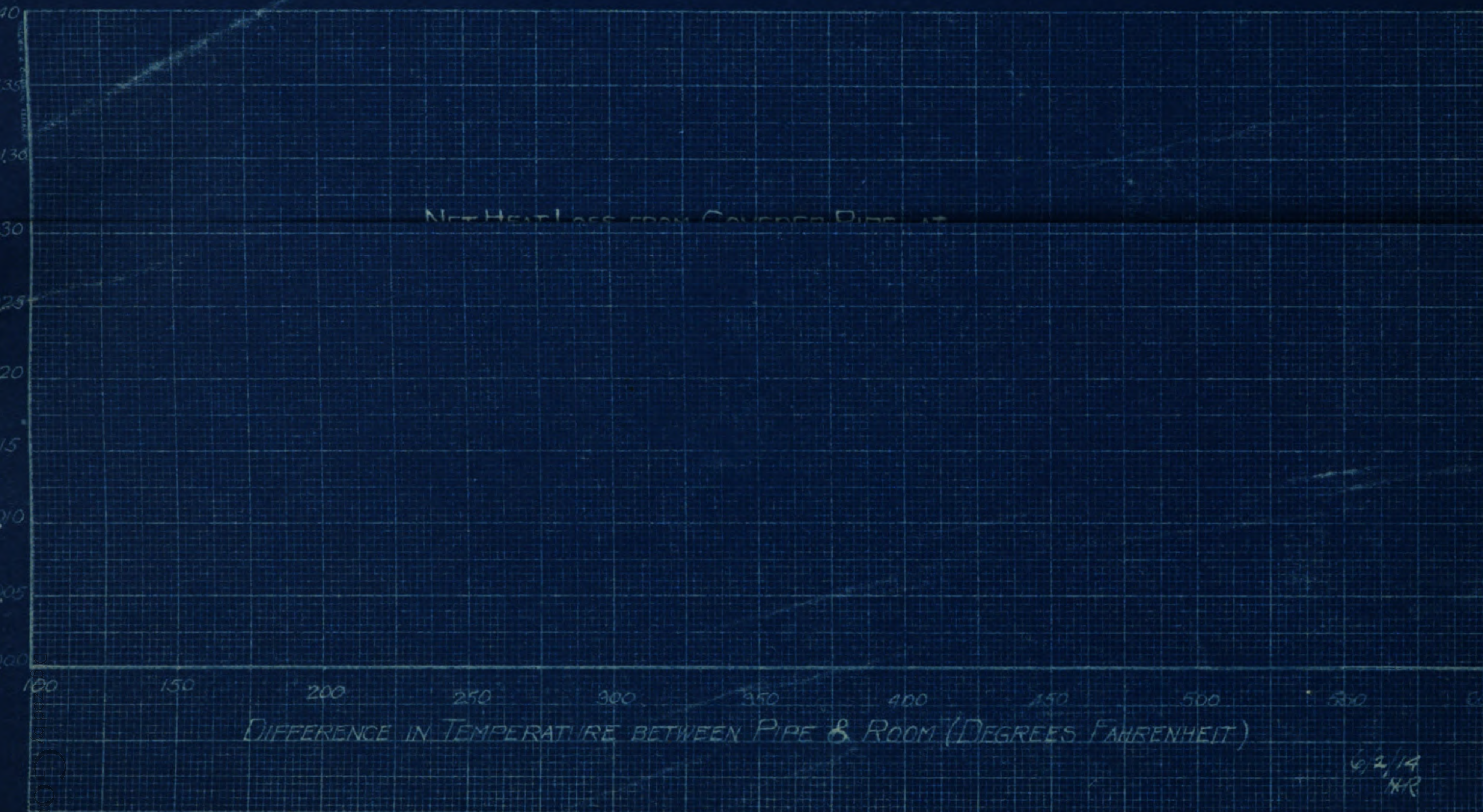

100
150
200
250
300
350
400
450
500
550
600
DIFFERENCE IN TEMPERATURE BETWEEN PIPE & ROOM (DEGREES FAHRENHEIT)
6/2/14
HR

Fig. 12

losses.

All points fell very close to the curves and this may be considered as an indication of the accuracy of the work. Duplicate runs were made at every temperature and these gave results that checked very closely. The curve representing the losses through the 85% Magnesia shows a very different shape from the others which are almost straight lines. However,before definite conclusions can be drawn from this fact,something more must be ascertained as to why it takes this shape,and that covering will be tested again at the earliest opportunity.

The results in general agree quite closely with those obtained by Stott on the same kinds of coverings. His tests were made at only one temperature so that,while they give one point for each material that falls very close to the corresponding curve for that material in Fig.I2,these tests show losses lower than his for the low temperature and greater at higher temperatures.

Of the five coverings tested only two,the 85% Magnesia and the fire felt were in good condition after the test. The others were made of asbestos put up in different shapes and when removed from the pipes this asbestos was very fragile and crumbled easily due to the high temperature to which it had been subjected. Therefore it would not be advisable to use one of these coverings where there was any likelihood of its having to be removed and put on again,or when superheat is used.

A table showing the savings effected by each of the different coverings at a temperature corresponding to I20# steam pressure, is shown in Fig.I3. This table also shows the cost of the

COMMERCIAL RESULTS

COMPARISON OF COVERINGS ON THE BASIS OF ECONOMY, AT 130 LBS SATURATED STEAM PRESSURE (SURROUNDING AIR AT 100°F)

Covering Material	Difference in Temp. be-ween Pipe and Surround-ng Air	RT.U. Loss/Hr/°F/Ft^2 Pipe Surface	T.U. Saving with Covering /Hr/°F/Ft^2 Pipe Surface	T.U. Saving with Covering /Year (8760 Hrs)/248°F /Ft^2 Pipe Surface	ost per Year of Covering 000Ft^2 Pipe Surface	et Saving per Year due to Covering/1000 Ft^2 Pipe Surface	eight of Covering/1000 Ft^2 Pipe Surface	hickness of Covering
	#2	1.362			1362.			
	#3	1.348			1348.			
	#4	1.390			1390.			
	#5	1.226			1226.			

Based on the guarantee under which coal is purchased by the University (Allowing 65% overall efficiency for generation of steam from coal)

* Surrounding Air Temp. = 100° F

Difference in Temp = 248

Pipe Temp = 348

347.8° Saturated Steam Temp. = 130 #/in^2 Pressure (Marks & Davis Tables)

Fig. 13

coverings per 1000 square feet and the net saving in dollars and cents per year; value of heat being figured at two cents per 100,000 B.T.U.* and the interest on investment, depreciation, maintenance, etc., being taken at 12%

Conclusion.

The investigations that have been described in this paper may be considered as only the beginning of the treatment of a very important problem. There are a large number of coverings on the market and the qualities of these should be known, not for the purpose of driving all but one kind out of use, but as an aid to the engineer in choosing that which is best suited to the needs of his particular case, for perhaps every covering manufactured has something in its favor peculiar to itself.

In conclusion, the writers wish to acknowledge the valuable assistance of Professors A.G.Christie, O.L.Kowalke and J.R.Roebuck whose advice and suggestions have made this work possible.

*Data obtained from University Heating Station..

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APPENDIX

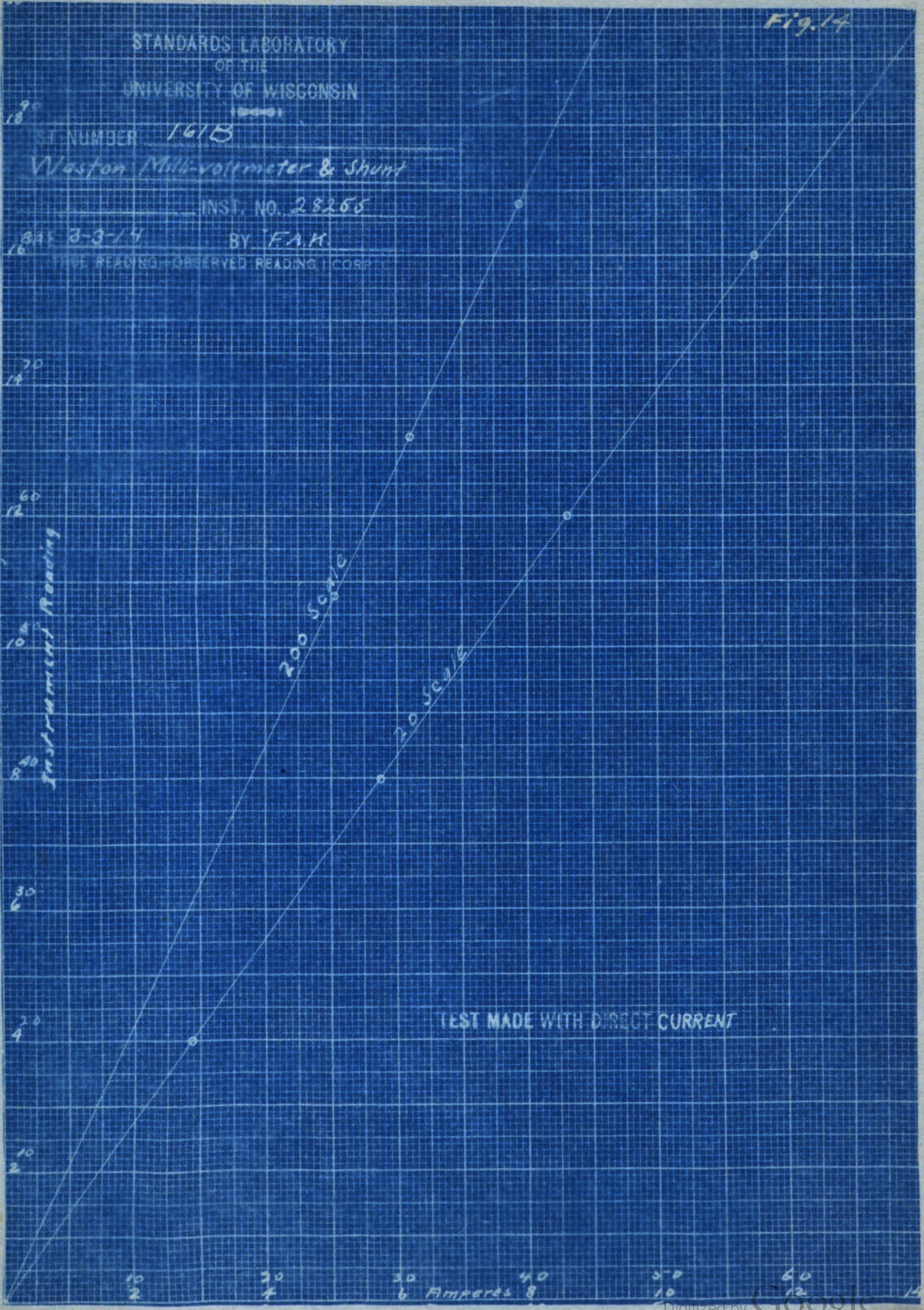


Fig. 14
STANDARDS LABORATORY
OF THE
UNIVERSITY OF WISCONSIN
TEST NUMBER 161B
Weston Milli-voltmeter & Shunt
INST. NO. 28255
DATE 3-3-14
BY F.A.H.
TRUE READING - OBSERVED READING = CORR.
Instrument Reading
200 Scale
20 Scale
TEST MADE WITH DIRECT CURRENT
Amperes

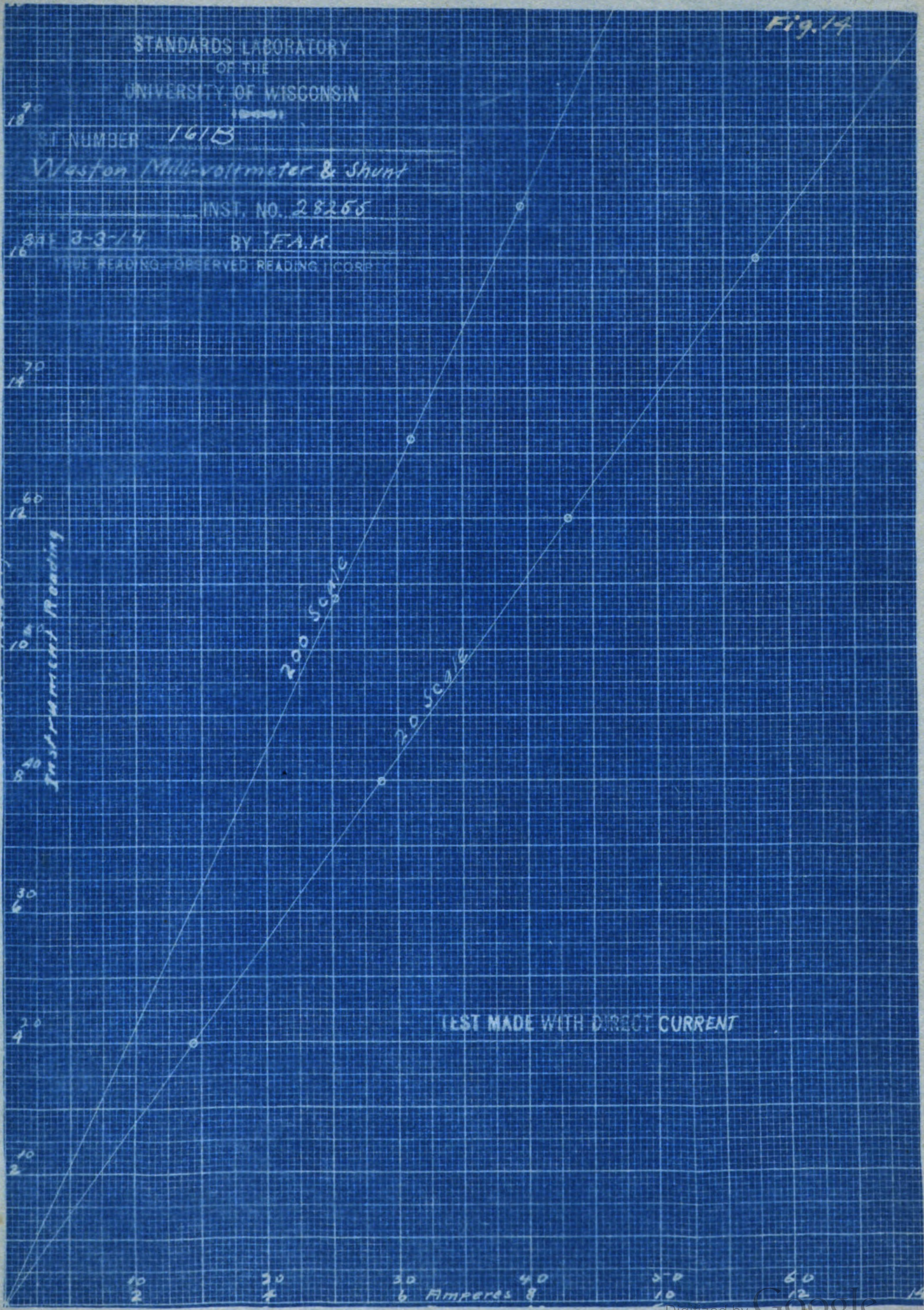
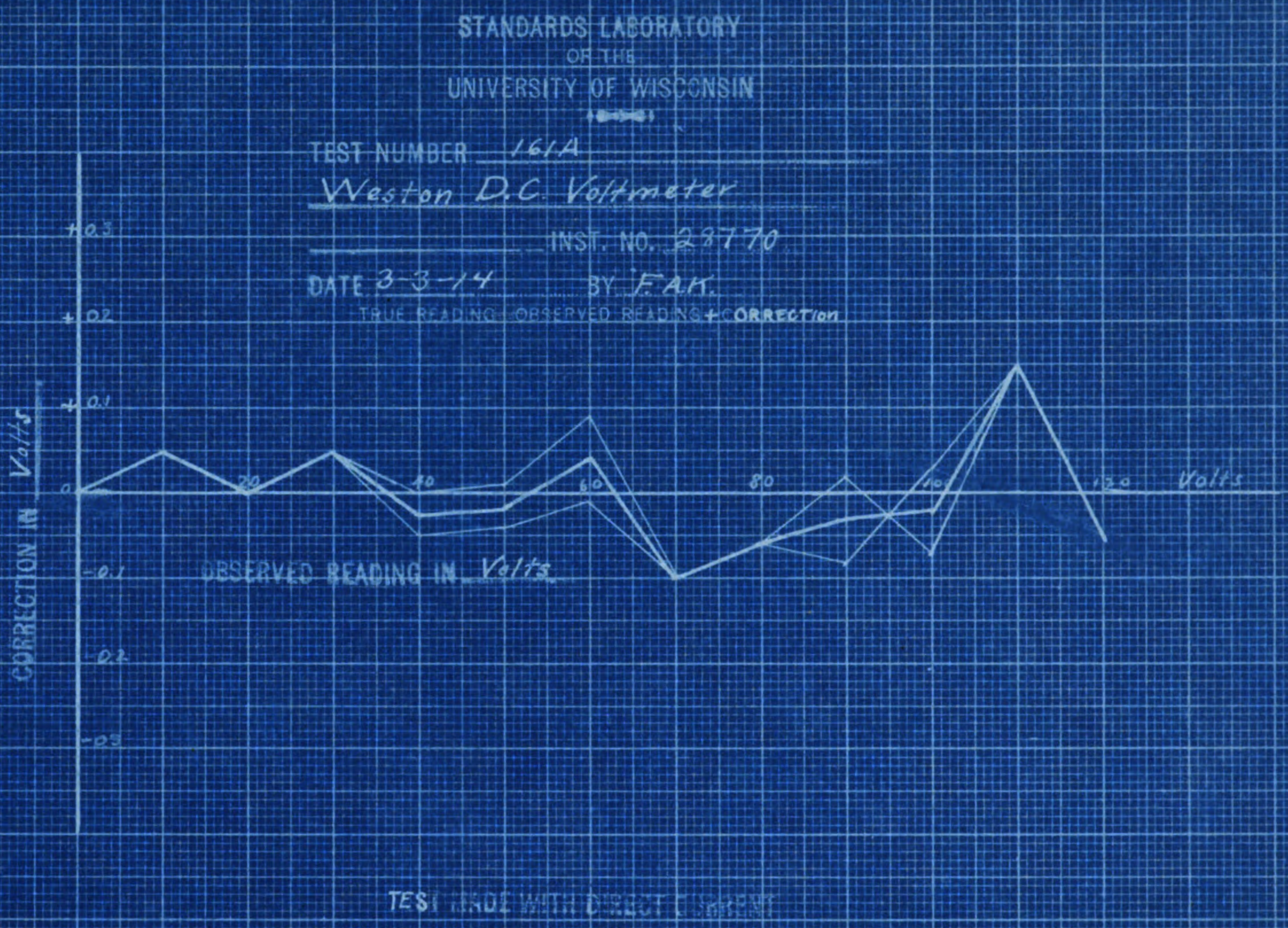


Fig. 14
STANDARDS LABORATORY
OF THE
UNIVERSITY OF WISCONSIN
TEST NUMBER 161B
Weston Milli-voltmeter & Shunt
INST. NO. 28255
DATE 3-3-14
BY F.A.H.
TRUE READING+OBSERVED READING+CORR.
200 Scale
20 Scale
Instrument Reading
TEST MADE WITH DIRECT CURRENT
Amperes



STANDARDS LABORATORY
OF THE
UNIVERSITY OF WISCONSIN
TEST NUMBER 161A
Weston D.C. Voltmeter
INST. NO. 28770
DATE 3-3-14 BY F.A.K.
TRUE READING = OBSERVED READING + CORRECTION
CORRECTION IN Volts
+0.3
+0.2
+0.1
0
-0.1
-0.2
-0.3
20
40
60
80
100
120
Volts
OBSERVED READING IN Volts
TEST MADE WITH DIRECT CURRENT

Fig. 15

Calibration of Weston
D.C. Ammeter No 6010.

Fig. 1

EXPERIMENT ON J.M.FIRE FELT.

Zero reading-- 25.0

Ele-ment.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	24.6	.4	.5	2I2°	2I7	80
2	II.2	I3.0	2I.0	...	233	8I
3	II.8	I3.2	20.0	...	232	82
4	8.5	I6.5	25.9	...	237.9	79
5	8.4	9.3	26.0	...	238	8I
6	I5.7	9.3	I3.3	...	225.3	..
7	I7.I	7.9	II.I	...	223.I	...
					229.5	80.6
	Volts	Amps.	Watts	...	B.T.U.	B.T.U. /oF
	38.8	46 x 47	839. / 844	...	2877	I9.3I

EXPERIMENT ON J.M.FIRE FELT.

Zero reading-- 29..I

Ele-ment.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	28.9	.2	....	2I2°	2I2.2	66.5
2	9.4	I9.7	32.0	...	244.	68.5
3	I3.0	I6.I	25.0	...	237.	70.
4	8.2	20.9	34.5	...	246.5	72.
5	6.2	22.9	38.4	...	250.4	69
6	I4.7	I4.4	22.0	...	234.	....
7	I4.4	I4.7	22.5	...	232.2	....
					236.6	69.2
	Volts	Amps.	Watts	...	B.T.U.	B.T.U. /°F.
	4I	48 x 47	925. / 930	...	3I70	I8.9I

EXPERIMENT ON J.M.FIRE FELT.

Zero reading -- 27.7

Cou-ple	Read-ing	Differ-ence	Temp. dif.	Bath	Pipe temp.	Room temp.
I	26.0	I.7	I.7	367°	368.7	84
2	I2.4	I5.3	I8.0	...	385.	87
3	I4.7	I3.0	I4.7	...	38I.7	86
4	3.7	24.0	32.0	...	399.8	84
5	3.0	24.7	34.2	...	40I.2	85
6	20.3	7.4	7.9	...	384.9	..
7	2I.2	6.5	6.9	...	383.9 386.5	.. 85.2

Volts		Amps.	Watts	...	B.T.U.	B.T.U./°F.
$\frac{119.6}{2}$=	59.8	67.8 x.47	I905. I908	...	65I0.	2I.58

EXPERIMENT ON J.M.FIRE FELT.

Zero reading-- 29.4

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	27.7	I.7	7.7	367.	368.7	7I.5
2	I2.4	I7.0	20.7	...	387.7	74.
3	24.2	5.2	5.3	...	372.3	76.
4	9.0	20.4	26.3	...	393.3	76.
5	7.3	22.I	29.3	...	396.3	74.
6	25.2	4.2	4.3	...	37I.2	..
7	24.5	4.9	4.9	...	37I.9	..
					350.2	74.3
Volts	Amps.	Watts	...	...	B.T.U.	B.T.U./^{o}F.
60	68 x 47	I9I7. / I920	...	...	6550.	2I.40

EXPERIMENT ON J.M.FIRE FELT.

Zero reading -- 38.0

Cou-ple	Read-ing.	Differ-ence.	Temp-dif.	Bath	Pipe temp.	Room temp.
I	27.6	..4	..4	426.	426.4	84.
2	I4.7	I3.3	I3.7	....	439.7	86.
3	I6.5	II.5	II.5	....	437.5	88.
4	4.5	28.4	36.7	....	462.7	85.
5	0.0	28.0	36.0	....	462.0	86.
6	24.4	3.6	3.I	....	429.0	...
7	25.0	3.0	2.5	....	428.5	...
					440.8	85.8
Volts	Amps.	Watts	...	....	B.T.U.	B.T.U./^{O}F.
66.7	74 x 47	±2320.	...	....	7925.	23.30

EXPERIMENT ON FIRE FELT.

Zero reading -- 29.6

Couple.	Reading.	Difference.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	26.4	3.2	2.8	426	428.8	77.
2	8.3	2I.3	25.0	...	45I.0	85.
3	2I.4	8.2	7.7	...	433.7	83.
4	3.3	26.3	33.2	...	459.2	8I.
5	0.0	29.6	38.6	...	464.6	79.
6	22.9	6.7	6.2	...	432.2	...
7	22.5	7.I	6.6	...	432.6	...
					443.2	79.2
Volts	Amps.	Watts	...	...	B.T.U.	B.T.U./°F.
67	74.2x47	2335 2338	...	...	7975.0	2I.90

EXPERIMENT ON J.M.FIRE FELT.

Zero reading --28.7

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	I7.3	II.4	8.8	583	59I.8	84.
2	I9.5	9.2	6.7	...	589.7	87.
3	35.0	6.3	4.3	...	578.7	88.
4	5.5	23.2	22.4	...	605.4	87.
5	4.0	24.7	24.4	...	607.4	87.
6	44.0	I5.3	I2.7	...	570.3	...
7	43.5	I4.8	I2.2	...	570.8	...
					587.7	86.6
Volts	Amps.	Watts	...	...	B.T.U.	B.T.U./$^{\circ}$F.
82.5	88 x 47 =	34I2. / 34I4.	...	...	II,630.	587.7

EXPERIMENT ON J.M.FIRE FELT.

Zero reading -- 29.8

Cou-ple	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	20.9	8.9	6.4	583	589.4	83.
2	8.0	2I.8	20.5	...	503.5	89.
3	4I.2	II.4	8.8	...	574.2	87.
4	I2.7	I7.I	I4.7	...	597.7	87.
5	0.8	30.6	32.8	....	6I5.8	...
6	42.5	I2.7	I0.I	...	582.9	....
7	42.0	I2.2	9.5	...	583.5	...
					592.4	86.6
Volts	Amps.	Watts	...	...	B.T.U.	B.T.U./$^{\circ}$F.
82	87.5 x 47	3852.	...	...	I3,I30.	25.95.
		3854				

EXPERIMENT ON J.M.SPONGE FELT.

Zero reading -- 20.8

Couple.	Reading.	Difference.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	I9.7	I.I	I.6	2II.	2I2.6	66.5
2	I8.8	2.0	2.4	....	2I3.4	68.8
3	22.6	I.8	2.2	....	208.8	69.0
4	I8.2	2.6	2.8	....	2I3.8	67.0
5	I6.7	4.I	4.2	....	2I5.2	69.0
6	2I.6	0.8	I.3	....	209.7	....
7	28.I	7.3	7.6	....	203.4	....
					2II.0	68.I
Volts	Amps.	Watts.	...	....	B.T.U.	B.T.U./° F.
26.5	33 x 47	4II.	...	....	I4I8	9.93

EXPERIMENT ON J.M.SPONGE FELT.

Zero reading -- I5.7

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	I6.7	I.0	I.0	2II.0	2I0.0	79.0
2	I8.9	3.2	3.0	.....	208.0	80.0
3	20.8	5.I	4.9	.....	206.I	80.0
4	I5.7	0.0	0.0	.....	2II.0	79.0
5	....	...	...	.....	.....	....
6	I8.7	3.0	2.8	.....	208.2	79.5
7	25.7	I0.0	I0.3	.....	22I.3	....
					2I0.8	79.5
Volts	Amps.	Watts	....	.....	B.T.U.	B.T.U./°F.
25	3I.5 x 47	370.7	....	.....	I280.	9.76

EXPERIMENT ON J.M.SPONGE FELT.

Zero reading -- 2I.2

Cou-ple	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	9.8	I0.4	8.3	365.0	373.3	59.5
2	I0.I	I0.I	8.I	.....	373.I	52.5
3	I9.9	I.3	I.4	.....	366.4	62.0
4	8.0	I4.2	II.8	.....	376.8	6I.0
5	9.9	I0.3	8.2	.....	373.2	62.5
6	20.4	8.0	I.0	.....	366.0	....
7	32.9	II.7	9.4	.....	365.6	....
					369.2	6I.5
Volts	Amps.	Watts.	....	.....	B.T.U.	B.T.U./°F.
44.5	52 x 47	I089	....	.....	3728.	I2.II

EXPERIMENT ON J.M.SPONGE FELT.

Zero reading --I9.I

Couple.	Reading.	Difference.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	2I.3	2.2	I.5	365	363.5	79.0
2	33.9	I4.8	I2.4	...	352.6	8I.5
3	35.I	I6.0	I3.7	...	35I.3	82.0
4	24.0	4.9	3.6	...	36I.4	80.0
5	24.I	5.0	3.6	...	36I.4	8I.5
6	34.4	I5.0	I2.6	...	352.4	....
7	45.6	26.5	27.8	...	.....	....
					357.I	80.8
Volts	Amps.	Watts	....	....	B.T.U.	B.T.U/°F.
40.5	48 x 47	9I4.0	....	...	3I26.0	II.30

EXPERIMENT ON J.M.SPONGE FELT.

Zero reading --2I.0

Cou-ple	Read-ing.	Differ-ence.	Temp-dif.	Bath	Pipe temp.	Room temp.
I	3.2	I7.8	II.4	643.	I54.4	65.5
2	..5	2I.5	I4.6	....	657.6	69.0
3	27.0	6.0	5.0	....	638.0	69.0
4	I.7	I9.3	I2.7	....	655.7	66.5
5	7.I	28.I	2I.0	....	664.0	69.0
6	I0.5	I0.5	5.7	....	648.7	....
7	34.5	I3.5	9.4	....	633.6	....
					650.3	67.8
Volts	Amps	Watts	....	....	B.T.U.	B.T.U./°F.
70	74 x47	2437.	....	....	83I8.	I4.27

EXPERIMENT ON J.M.SPONGE FELT.

Zero reading -- 33.3

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	25.5	2.2	I.0	643	642.0	8I
2	36.3	I3.0	7.4	...	635.6	83
3	53.3	30.0	22.8	...	62I.2	82
4	I9.7	3.6	I.6	...	644.6	8I
5	I8.7	.6	2.I	...	645.6	83
6	40.3	I7.0	I0.4	...	632.6	..
7	50.3	37.0	32.0	...	6II.0	..
					633.2	82
Volts Amps.		Watts.	....	...	B.T.U.	B.T.U./°F.
67	72 x 47	2285.	....	...	7800.	I4.I5

EXPFRIMENT ON J.M.ASBESTOCEL.

Zero reading -- I9.9

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	I3.I	6.8	5.0	2II	2I6.0	74.0
2	I8.4	I.5	2.0	...	2I3.0	75.0
3	I4.3	5.6	7.6	...	2I8.6	74.0
4	I4.4	5.5	7.5	...	2I8.5	74.0
5	....	...	...	...	.....	75.0
6	I6.3	3.6	4.8	...	2I5.8	....
7	23.3	3.4	4.5	...	206.5	....
					2I4.7	74.4
Volts	Amps.	Watts.	...	...	B.T.U.	B.T.U./°F.
29	35.5 x 47	I670.	...	...	I669.0	II.89

EXPERIMENT ON J.M.ASBESTOCEL.

Zero reading -- I7.4

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	I7.0	.2	0.0	2I3	2I3.0	82.5
2	....	..	...	...	.....	83.0
3	I9.2	2.0	2.8	...	2I0.2	84.0
4	....	....	...	...	.....	84.0
5	....	....	...	...	.....	84.0
6	20.0	2.6	3.4	...	209.6	....
7	24.5	7.I	9.9	...	203.I	....
					209.0	83.5
Volts	Amps.	Watts	...	...	B.T.U.	B.T.U./^{o}F.
28	34 x 47	I600	...	...	I545	I2.30

EXPERIMENT ON J.M.ASBESTOCEL.

Zero reading -- I9.6

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Path	Pipe temp.	Room Temp.
I	I2.6	7.0	7.4	365	372.4	73.5
2	I5.5	3.6	3.6	...	368.6	75.0
3	II.4	8.2	8.8	...	373.8	75.0
4	5.4	I4.2	I6.5	...	38I.5	74.0
5	....	....	....	...	.....	76.0
6	I4.9	4.7	4.8	...	369.8	....
7	23.3	3.7	3.6	...	36I.4	....
					37I.3	74.7
Volts	Amps.	Watts	....	...	B.T.U.	B.T.U./°F.
48	55 x47	I238	....	...	4240.0	I4.27

EXPERIMENT ON J.M.ASBESTOCEL.

Zero reading 32.5

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	I.2	3I.3	48.0	365	4I3.0	77.0
2	I2.9	I9.6	25.0	...	390.0	80.5
3	7.2	25.3	35.4	...	400.4	8I.0
4	4.0	28.5	42.0	...	407.0	82.0
5	....	....	....	...	.....	8I.0
6	9.5	23.0	3I.0	...	396.0	....
7	22.8	9.7	I0.5	...	375.5	....
					397.0	80.0
Volts	Amps	Watts.	....	...	B.T.U.	B.T.U./°F.
49	56.5 x 47	I304.	....	...	4460.	I4.06

EXPERIMENT ON J.M.ASBESTOCEL.

Zero reading -- I6.6

Couple.	Reading.	Difference.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	0.7	I5.9	I7.0	426	443.0	75
2	9.6	7.0	6.5	...	432.5	76
3	I.4	I5.2	I6.2	...	442.2	79
4	0.2	I8.8	2I.0	...	44I.0	76
5	...	....	....	...	.....	77
6	7.0	9.6	9.3	...	435.3	..
7	I7.6	I.0	0.7	...	425.3	..
					437.6	76.6
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./°F.
54.5	63 x 47	I6I4	....	...	5520	I528

EXPERIMENT ON J.M.ASBESTOCEL.

Zero reading -- 24.I

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	4.3	I9.8	23.0	426	449.0	8I.5
2	I8.9	5.2	4.6	...	430.6	83.5
3	I3.8	I0.8	I0.6	...	436.6	82.5
4	8.7	I5.4	I6.5	...	442.5	82.0
5	....	....	....	...	.....	82.0
6	I6.2	7.9	7.4	...	433.4	....
7	28.2	4.I	3.5	...	422.5	....
					435.8	82.3
Volts	Amps	Watts.	....	...	B.T.U.	B.T.U./°F.
54	63 x 47	I575	....	...	3385.	I5.22

EXPERIMENT ON J.M.ASBESTOCEL.

Zero reading -- 20.0

Couple.	Reading.	Difference.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	29.0	9.0	6.6	643	636.4	68
2	37.2	I7.2	I4.9	...	628.I	7I
3	34.I	I4.I	II.5	...	63I.5	72
4	I7.0	3.0	I.8	...	644.8	70
5	.....	....	....	...	.....	7I
6	3I.9	II.9	9.4	...	633.6	..
7	43.6	23.6	23.0	...	620.0	..
					632.4	70.4
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./^{o}F.
77.5	82.5 x 47	3008	....	...	I0,250.0	I826

EXPERIMENT ON J.M.ASBESTOCEL.

Zero reading -- 34.9

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I.	7.3	I7.6	I5.2	583	598.3	86.0
2	34.9	0.0	0.0	...	583.0	88.0
3	2I.I	3.8	2.4	...	585.4	90.0
4	9.4	I5.5	I3.0	...	596.0	86.5
5	....	....	....	...	.....	88.0
6	I6.9	8.0	5.6	...	588.0	....
7	4I.2	I6.3	I3.8	...	569.2	....
					586.8	87.7
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./°F.
67.8	75 x 47	3392	....	...	8,I65.0	I6.35

EXPERIMENT ON J.M.ASBESTOCEL.

Zero reading -- 24.9

Couple.	Reading.	Difference.	Temp. dif.	Bath	Pipe temp.	Room temp.
I.	7.3	I7.6	I5.2	583	598.3	86.0
2	24.9	0.0	0.0	...	583.0	88.0
3	2I.I	3.8	2.4	...	585.4	90.0
4	9.4	I5.5	I3.0	...	596.0	86.5
5	....	....	....	...	.....	88.0
6	I6.9	8.0	5.6	...	588.0	....
7	4I.2	I6.3	I3.8	...	569.2	....
					586.8	87.7
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./$^{\circ}$F.
67.8	75 x 47	2392	....	...	8,I65.0	I6.35

EXPERIMENT ON J.M.AIR CELL.

Zero reading --25.2

Couple.	Reading.	Difference.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	22.7	2.5	3.4	2II	2I4.4	73.5
2	I6.8	8.4	II.9	...	222.9	73.0
3	I9.4	5.8	8.0	...	2I9.0	73.0
4	I7.0	8.2	II.5	...	222.5	74.0
5	25.0	0.2	0.3	...	2II.3	72.0
6	20.4	4.8	6.4	...	2I7.4	....
7	25.3	0.I	0.2	...	2I0.8	....
					2I6.9	73.I
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./$^{\circ}$ F.
29.4	36.8 x 47	509	....	...	I750.0	I2.I7

EXPERIMENT ON J.M.AIR CELL.

Zero reading -- I9.8

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	23.8	4.0	5.5	2II.5	206.0	8I.0
2	I8.6	I.2	I.7	.....	2I3.2	8I.0
3	20.4	0.6	0.7	.....	2I0.8	83.5
4	I7.9	I.9	2.5	.....	2I4.0	79.0
5	....	...	...	.....	.....	8I.5
6	2I.5	I.7	2.2	.....	209.3	....
7	25.8	6.0	8.0	.....	203.2	....
					209.4	8I.2
Volts	Amps.	Watts	...	.....	B.T.U.	B.T.U./$^{\circ}$ F.
29	36 x 47	49I	...	.....	I690.0	I3.I8

EXPERIMENT ON J.M.AIR CELL.

Zero reading -- 25.4

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	I5.5	9.9	II.0	365	376.0	73
2	I3.3	I2.2	I3.9	...	378.9	75
3	2I.3	4.I	4.2	...	369.2	76
4	I4.2	II.2	I2.3	...	377.3	75
5	.....	....	....	...	.....	74
6	24.I	I.3	I.2	...	366.2	..
7	32.4	7.0	7.4	...	357.6	..
					370.9	74.6
Volts	Amps	Watts	...	...	B.T.U.	B.T.U./°F.
49	56.8 x 47	I307	...	...	4470	I5.06

EXPERIMENT ON J.M.AIR CELL.

Zero reading -- 2I.2

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	27.6	6.4	6.7	365	358.3	77.5
2	I9.7	I.5	I.4	...	366.4	79.0
3	24.2	3.0	2.9	...	362.I	80.0
4	20.5	0.7	0.6	...	365.6	78.5
5	.....	...	...	...	.....	80.0
6	27.7	6.5	6.9	...	358.I	....
7	33.I	II.9	I3.2	...	35I.8	....
					360.4	79.0
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./°F.
48	56 x 47	I262	....	...	43I5	I5.32

EXPERIMENT ON J.M.AIR CELL.

Zero reading -- 25.8

Couple.	Reading.	Difference.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	5.8	20.0	23.0	426	449.0	73.0
2	3.0	28.8	38.0	...	464.0	74.5
3	6.6	I9.2	2I.8	...	447.8	74.0
4	I.0	24.8	30.8	...	456.8	72.5
5	...	....	....	...	.....	74.0
6	I0.0	I5.8	I7.0	...	443.0	....
7	I0.5	7.3	6.8	...	432.8	....
					448.9	73.6
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./^{o}F.
58.2	65.5 x 47	I790	....	...	6I20	I6.28

EXPERIMENT ON J.M.AIR CELL.

Zero reading -- 25.8

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	5.8	20.0	23.0	436	449.0	73.0
2	3.0	28.8	38.0	...	464.0	74.5
3	6.6	I9.2	2I.8	...	447.8	74.0
4	I.0	24.8	30.8	...	456.8	72.5
5	...	....	....	...	.....	74.0
6	I0.0	I5.8	I7.0	...	443.0	....
7	I0.5	7.3	6.8	...	432.8	....
					448.9	73.6
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./^{o}F.
58.2	65.5 x 47	I790	....	...	6I20	I6.28

EXPERIMENT ON J.M.AIR CELL.

Zero reading -- 20.7

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	I4.0	6.7	6.2	426	432.2	73
2	7.2	I3.5	I4.0	...	440.0	74
3	I3.4	7.3	6.7	...	432.7	76
4	2.8	I7.9	I9.8	...	445.8	73
5	....	....	....	...	.....	75
6	I7.8	2.9	2.4	...	428.4	..
7	23.0	2.3	I.8	...	424.2	..
					433.9	74.2
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./^{o}F.
56.4	64 x 47	I695	....	...	5795	I6.9

EXPERIMENT ON J.M.AIR CELL.

Zero reading -- 20.8

Couple.	Reading.	Difference.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	22.8	0.2	I.I	583	58I.9	82.0
2	I7.5	2.3	0.4	...	584.4	84.0
3	32.6	II.8	9.2	...	573.8	86.0
4	I8.I	2.7	I.7	...	584.7	82.0
5	....	....	...	...	.....	83.5
6	30.0	9.2	6.7	...	576.3	....
7	45.0	24.2	23.8	...	559.2	....
					576.7	83.5
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./°F.
7I.5	78 x47	2620	.....	...	8445	I8.II

EXPERIMENT ON J.M.85% MAGNESIA

Zero reading -- I7.3

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	I7.3	...	...	365	365.0	76
2	II.0	6.3	6.6	...	37I.6	74
3	I3.6	3.7	3.8	...	368.8	76
4	9.6	7.7	8.3	...	373.3	75
5	....	...	...	...	.....	74
6	20.7	3.4	3.4	...	36I.6	..
7	27.6	I0.3	II.3	...	353.7	..
					365.7	75.0
Volts	Amps	Watts	.....	...	B.T.U.	B.T.U./^{o}F.
45.8	52.2 x 47	II23	....	...	3843	I3.22

EXPERIMENT ON J.M.85% MAGNESIA.

Zero reading -- 25.I

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	25.0	0.I	....	2I0.5	2I0.5	79.0
2	I7.4	7.7	I0.8	.....	22I.3	80.5
3	I7.5	7.6	I0.6	.....	22I.I	82.0
4	I6.9	8.2	II.5	.....	222.0	79.5
5	....	...	....	.....	.....	8I.0
6	20.9	4.2	5.7	.....	2I6.2	....
7	26.2	I.I	I.4	.....	209.I	....
					2I6.7	80.4
Volts	Amps	Watts	....	.....	B.T.U.	B.T.U./^{o}F.
25.8	34 x 47	4I3	....	.....	I425	I0.45

EXPERIMENT ON J.M.85% MAGNESIA.

Zero reading -- 25.5

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	3I.2	5.7	5.9	365	359.I	8I.0
2	II.2	I4.3	I6.7	...	38I.7	83.0
3	I2.5	I3.0	I4.8	...	379.8	84.0
4	I2.7	I2.8	I4.5	...	379.5	8I.5
5	6.5	I9.0	25.8	...	388.8	83.0
6	20.3	5.2	5.3	...	370.3	....
7	28.2	2.7	2.7	...	362.3	....
					374.5	82.5
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./$^{\circ}$F.
44	5I x 47	I054	....	...	3608	I2.34

EXPERIMENT ON J.M.85% MAGNESIA.

Zero reading -- 20.2

Cou-ple	Read-ing.	Differ-ence..	Temp. dif.	Bath	Pipe temp.	Room temp.
I	I7.3	2.9	2.4	426	428.4	77.5
2	I4.0	6.2	5.6	...	43I.6	79.0
3	I5.0	5.2	4.6	...	430.0	80.0
4	I0.0	I0.2	I0.0	...	436.0	77.5
5	....	....	....	...	.....	79.0
6	24.9	4.7	4.2	....	42I.8	....
7	34.5	I4.3	I5.0	...	4II.0	....
					426.6	78.6
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./°F.
48.5	55 x 47	I253	....	...	4285	I2.3I

EXPERIMENT ON J.M.85 % MAGNESIA.

Zero reading -- 26.0

Couple.	Reading.	Difference.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	24.5	I.5	I.I	426	427.I	82
2	II.5	I4.5	I5.3	...	44I.3	84
3	I4.7	II.3	II.2	...	437.2	86
4	I0.7	I5.3	I6.2	...	442.2	83
5	8.I	I7.9	I9.8	...	445.8	84
6	23.2	2.8	2.4	...	428.4	..
7	32.2	6.2	5.6	...	420.4	..
					434.6	83.8
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./°F.
49	49 x 56	I289	....	...	44I0	I2.50

EXPERIMENT ON J.M.85% MAGNESIA.

Zero reading -- 20.3

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	8.0	I2.3	9.6	583.0	592.6	77.5
2	7.0	I3.3	II.6	.....	594.6	80.0
3	I7.4	2.9	I.8	.....	584.8	8I.0
4	I0.3	I0.0	7.6	.....	590.6	78.5
5	....	....	....	.....	.....	80.0
6	22.9	2.6	I,5	.....	58I.5	....
7	38.0	I7.7	I5.4	.....	567.6	....
					585.3	79.4
Volts	Amps	Watts	....	.....	B.T.U.	B.T.U./^{o}F.
60.5	66 x 47	I876	....	.....	6408	I2.65

EXPERIMENT ON J.M.85% MAGNESIA.

Zero reading -- 25.

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	27.0	2.0	I.I2	583	58I.9	83
2	I4.0	39.0	46.0	...	629.0	86
3	4.3	20.7	I9.0	...	602.0	87
4	3.0	2.8	29.I	...	6I2.I	84
5	....	....	....	...	.....	85
6	I6.7	8.3	6.0	...	589.0	..
7	23.5	I.5	0.8	...	583.8	..
					599.6	85
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./°F.
63	68 x 47	20I3	....	...	6875	I3.35

EXPERIMENT ON BARE PIPE.

Zero reading --30.8

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	30.3	0.5	0.7	2I2	2I2.7	79
2	I9.4	II.4	I6.8	...	228.8	82
3	42.6	II.8	I7.5	...	I94.5	83
4	23.6	7.2	I0.I	...	222.I	8I
5	I6.7	I4.I	2I.4	...	233.4	82
6	34.8	4.0	5.5	...	206.5	..
7	I6.8	I4.0	2I.3	...	233.3	..
					2I8.8	8I.4
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./°F.
66	78 x 47	2420	....	...	8275	60.23

EXPERIMENT ON BARE PIPE.

Zero reading --26.7

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	I0.6	I6.I	25.0	2II	236.0	86
2	I9.2	7.5	I0.5	...	22I.5	89
3	35.4	8.7	I2.3	...	I98.7	90
4	I9.3	7.4	I0.4	...	22I.5	87
5	I6.0	I0.7	I5.7	...	226.7	..
6	33.5	6.8	9.4	...	20I.6	..
7	I7.3	9.4	I3.4	...	224.4	..
					2I8.6	87.8
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./FT.
62	75 x 47	2I85	....	...	7475	57.I5

EXPERIMENT ON BARE PIPE.

Zero reading -- I0.0

Couple.	Reading.	Difference.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	8.0	2.0	2.0	367	369.0	9I.0
2	I7.6	7.6	8.I	...	358.9	96.5
3	65.0	55.0	89.6	...	277.4	98.0
4	I4.I	4.I	4.2	...	363.8	94.0
5	3.5	6.5	9.0	...	376.0	95.0
6	59.0	49.0	78.5	...	288.5	....
7	I8.5	8.5	I2.0	...	355.0	....
					34I.2	94.9
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./^{o}F.
I07	I20 x 47	6040	....	...	20,600	83.7

EXPERIMENT ON BARE PIPE.

Zero reading --27.I

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
I	26.I	I.0	I.0	367	368.0	..
2	32.6	5.5	5.6	...	36I.4	97
3	77.0	50.0	79.9	...	287.3	97
4	22.5	4.6	6.2	...	373.2	95
5	I6.8	I0.4	II.5	...	378.5	96
6	65.0	38.0	58.8	...	308.2	..
7	28.3	I.8	I.7	...	365.3	..
					348.8	96.3
Volts	Amps.	Watts.	....	...	B.T.U.	B.T.U./°F.
I07	I20 x 47	6040	....	...	20,600	8I.7

EXPERIMENTS ON SHORT PIPE.

Zero reading -- 25.0

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe. temp.	Room temp.
8	I8.6	6.4	8.8	210.5	2I9.3	77
9	I7.I	7.9	II.0	.....	22I.5	79
					220.4	78
Volts	Amps	Watts	....	......	B.T.U.	B.T.U./°F.
2I.I	4.32	9I.I	....	.....	3II	2.I8

Zero reading --25.0

8	26.0	I.0	.8	426	4I8.0	77.5
9	2I.5	3.5	3.I	...	429.I	80.0
					423.5	78.8
Volts	Amps	Watts	...	...	B.T.U.	B.T.U./°F.
40	7.95	3I8	...	...	I085	3.I5

EXPERIMENTS ON SHORT PIPE.

Zero reading -- 25.5

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
8	20.2	5.3	5.I	2I2.0	2I9.I	8I
9	I7.9	7.6	7.6	.....	222.6 220.9	84 82.5
Volts	Amps	Watts	...	.....	B.T.U.	B.T.U./°F.
2I.0	4.3	90.4	...	.....	309	2.9

Zero reading -- 26.0

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
8	29.4	3.4	3.4	367	363.6	82
9	27.0	I.0	I.I	...	365.9 364.8	86 84
Volts	Amps	Watts	...	...	B.T.U.	B.T.U./°F.
3I	6.25	I9.4	...	...	662	2.36

EXPERIMENTS ON SHORT PIPE.

Zero reading -- 25.0

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
8	I9.2	5.8	5.3	426	43I.3	83
9	I5.9	9.I	8.7	...	434.7 433.0	87 85
Volts	Amps	Watts	...	...	B.T.U.	B.T.U./°F.
35	7.0	245	...	...	836	2.40

Zero reading --26.2

8	5.0	2I.2	I9.6	583	607.6	77.5
9	23.9	2.3	I.4	...	584.4 593.5	82.0 79.8
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./°F.
47.8	9.3	444.5	....	...	I5I6	2.95

EXPERIMENTS ON SHORT PIPE.

Zero reading -- 27.7

Cou-ple.	Read-ing.	Differ-ence.	Temp. dif.	Bath	Pipe temp.	Room temp.
8	I0.0	I7.7	I9.6	426	445.6	87.0
9	I8.I	9.6	9.2	...	<u>435.2</u> 440.4	<u>84.0</u> 85.5
Volts	Amps	Watts	.....	...	B.T.U.	B.T.U./°F.
36.I	7.20	260	....	...	886	2.49

Zero reading -- 28.2

8	20.2	8.2	5.9	583	588.9	84
9	I7.8	I0.4	7.9	...	<u>590.9</u> 589.9	<u>88</u> 86
Volts	Amps	Watts	...	...	B.T.U.	B.T.U./°F.
45	8.7	392.0	...	...	I335	2.65

Zero reading -- 29.8

8	26.4	3.4	3.4	367	370.4	83
9	I4.6	I5.2	I7.9	...	<u>384.9</u> 377.7	<u>89</u> 86
Volts	Amps	Watts	....	...	B.T.U.	B.T.U./°F.
3I.8	6.35	3)4	....	...	689	2.37

APPROVED BY ....A. G. Christie........

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